COMMENTARY

# Initial Declines in China's Provincial Energy Consumption and Their Drivers

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## INTRODUCTION

The years from 2003 to 2016 chronicle China's three distinct periods, characterized by fast economic expansion from 2003 to 2007, the fall and recovery of the economy under the strike of global financial crisis from 2007 to 2011, and the strategic adjustment from 2011 to 2016, known as China's "new normal" period (a slowdown of economic growth to around 7%) aimed at "low but high-quality growth." In the wake of this economic cycle, China's energy consumption was also in a state of flux. From 2003 to 2007, China's gross domestic product (GDP) and total primary energy consumption grew by 11.68% and 12.96% per year, respectively.[1] Struck by the financial crisis, the growth of GDP and energy consumption slowed down to 10.68% and 6.20%, respectively, from 2007 to 2011. As China entered the "new normal" period in 2011, the economy grew at an annual rate of 7.68%, and the growth of energy consumption eased to 3.2% per year until 2016. It can be observed that the energy elasticity (the percentage change in energy consumption to achieve a 1% change in national GDP)[2] in China had decreased continuously from 2003 to 2016. Starting at a level of 1.11 from 2003 to 2007, the energy elasticity dropped to 0.58 from 2007 to 2011, followed by an even lower value of 0.42 from 2011 to 2016. China seems to be on a path toward more energy-efficient growth.

The reduction in the growth of energy consumption is even more prominent at the provincial level. Eight of the provinces saw declines in their total primary consumption (including coal, petroleum, natural gas, and non-fossil fuels) from 2011 to 2016. In addition, the other six provinces decreased their combined consumption of coal and petroleum, although their total primary consumption slightly increased. In other words, nearly half of China's 30 inland provinces have made positive transitions in their energy consumption. It is important to understand the drivers behind such transitions and the possibility to sustain them.

There is an extensive body of literature on driver analysis of China's energy consumption at the national level and, to a lesser extent, at the provincial level. At the national level, these studies cover a wide time span from 1970 to 2015 but are generally inconsistent in the number of decomposed factors, time lag, and sectors of interest.[3,4] Such inconsistencies make it hard to compare the results from different studies. At the provincial level, many of the studies focus on energy-related carbon dioxide ($CO_2$) emissions,[5] energy intensity,[6] and $CO_2$ emission intensity.[7] The studies missed the declines in energy consumption of some provinces because of the grouping of provinces or lack of sub-period analysis. For example, some studies only targeted the start and end years (e.g., 2000–2015 or 2005–2010), which obscured the emerging trend in between these periods. Other studies grouped the provinces by their spatial locations or types of drivers for ease of discussion. In a previous study, for instance, provinces were grouped into eastern, central, and western regions, and energy-related $CO_2$ emissions for central regions have leveled off since 2011.[8] Among these provinces, it is highly likely that some of their emissions had already declined. It is unfortunate that the trend was smoothed and overlooked.

In this Commentary, we study the changes in energy drivers for the provinces with observed declines in their primary energy consumption and discuss how their drivers are different from the others. The logarithmic mean Divisia index decomposition analysis was combined with the cumulative sum test to study the socioeconomic factors driving the declines and the possibility for such trends to be sustained. Energy and socioeconomic data are collected from China's provincial statistical yearbooks (more in Supplemental Information). This study highlights the opportunity for structural declines in terms of energy consumption at the provincial level in China.

## NEGATIVE FORCES PLAYING CATCH-UP

Despite the variations in absolute contributions, the extensive body of literature agrees that economic growth is always the predominant driver of increased energy consumption, while energy intensity is the most significant factor of decreased energy consumption in China.[3–8] Nevertheless, the decreasing effect of energy intensity on energy consumption is hardly close to the increasing effect of economic growth. This phenomenon is observed in previous studies as well as in the analysis before 2011 in this work. However, changes began to occur during the period from 2011 to 2016. In eight provinces, the decreasing effect of energy intensity exceeded or approximated the increasing effect of economic growth ("catch-up" of energy intensity). In six of these provinces, energy intensity alone offset all the increased consumption triggered by the economy (Figure 1A). Collectively, the decrease in energy intensity in six provinces, i.e., Fujian, Chongqing, Jilin, Henan, Hubei, and Yunnan, led to a decrease of 473 million metric tons of coal equivalent (Mtce), surpassing the increase caused by economic growth (419 Mtce). For the other two provinces, i.e., Hebei and Shanghai, the decrease from energy intensity compensated 95% and 73% of the increased consumption led by economic growth, respectively (Figure 1B). Detailed decomposition results by province can be found in Table S2.

Moreover, new drivers that decrease consumption are emerging. One driver is the share of coal. All eight provinces with declined consumption are found to have decreasing consumption triggered by a decreased share of coal in the energy mix (gray in Figure 1A). In Hubei, Shanghai, Fujian, and Yunnan, the decreasing effect from the share of coal was particularly significant, which offset 27%, 21%, 21%, and 16% of the increase from economic growth, respectively. Such decreases reflect the rapid expansion in wind and solar energies happening within China.[9] The other driver is the change of industrial structure. With the exceptions of Chongqing, Yunnan, and Hubei, industrial structure is a driver that decreases consumption featured by a reduced share of heavy industries (dark blue in Figure 1B).

In a deeper sense, the catch-up might be attributed to either the slowdown in economic growth or the significant reduction in energy intensity (or both). Indeed, both drivers contribute, but the effect of the energy intensity is more dominant. Economic growth was responsible for 283, 386, and 419 Mtce growth in energy consumption for the eight provinces every five years from 2003 to 2011 and six years from 2011 to 2016. The driving effect from the economy kept growing but at a slower pace. Meanwhile, the decrease from energy intensity was dominant. Within the same time frame, energy intensity had led to decreases in energy consumption of 42, 209, and 473 Mtce. In the most recent six years from 2011 to 2016, the decreasing effect from energy intensity alone (473 Mtce) was able to offset all of the increasing effect of economic growth on energy consumption (419 Mtce), not to mention the additional decreases by the share of coal and the change of industrial structure. It can be concluded that the catch-up is more attributable to the enhancement of drivers that reduce consumption rather than the slowdown of the economy.

Six provinces are found to have reduced consumption of coal and petroleum, although their total primary consumption increased slightly. These provinces are Beijing, Tianjin, Guangdong, Liaoning, Zhejiang, and Hunan

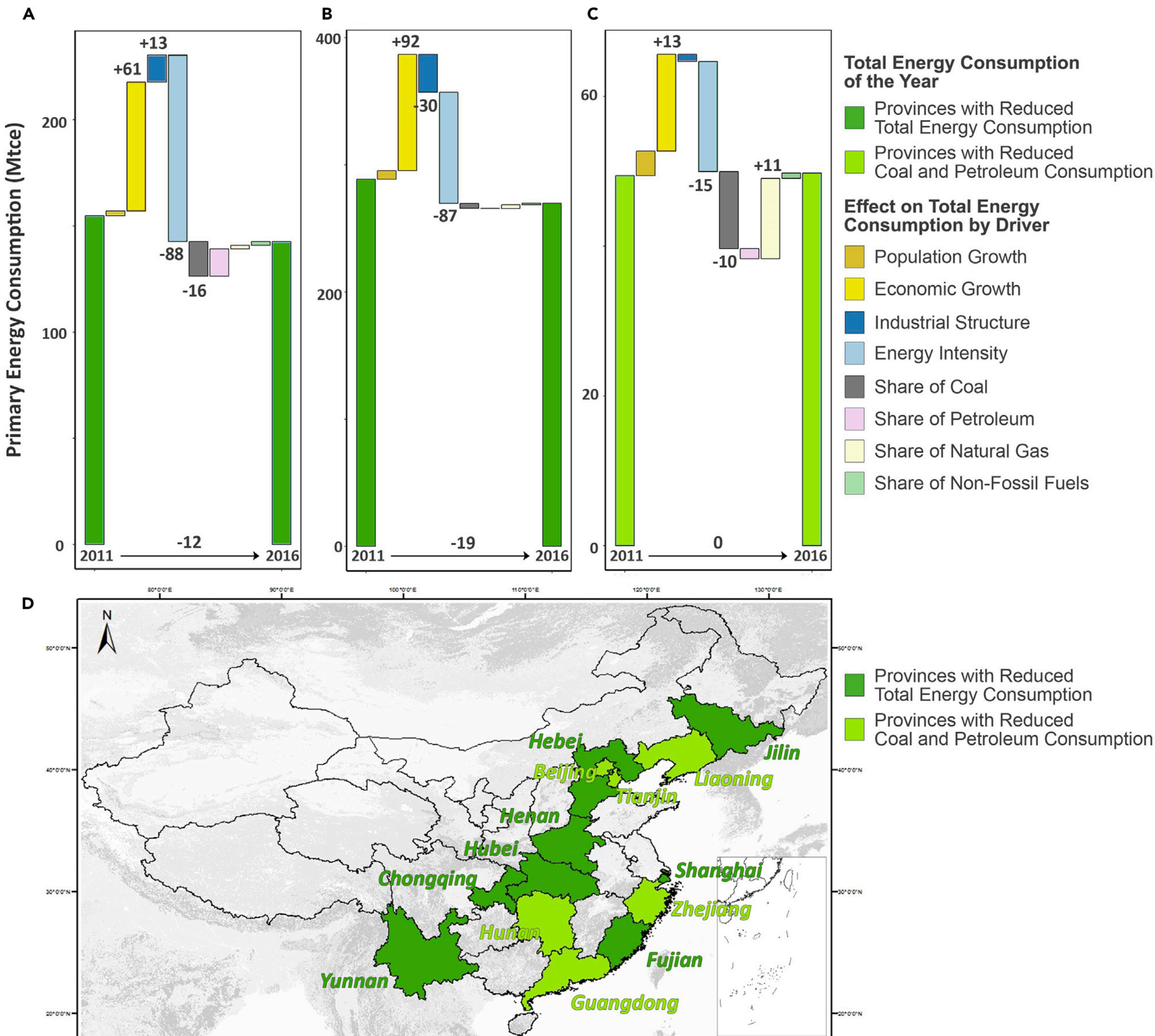


**Figure 1. Key Negative Drivers Leading to Reduced Consumption**

Drivers of reduced consumption, mainly from energy intensity, have caught up with the drivers that increase consumption and led to reduced total energy consumption in (A) Hubei, (B) Hebei, and other provinces (provinces in dark green in D). Similar patterns are observed in (C) Beijing and in the other five provinces (provinces in light green in D), which were able to reduce their combined consumption of coal and petroleum.

(Figure 1D). Their energy drives are very similar to those discussed above, in which the decreasing effects of energy intensity, share of coal, and industrial structure change exceeded or approximated the increasing effects of economic growth on energy consumption. The main difference, however, is the effect of the share of cleaner fuels including natural gas and non-fossil fuels. While the shares of coal and petroleum decreased in the energy mix, the shares of natural gas and non-fossil fuels increased significantly and neutralized the reduction effects of energy intensity and other decreasing drivers (Figure 1C). Take Zhejiang as an example: the decreasing effects of energy intensity and share of coal and industrial structure surpassed the increasing effect of economic growth on energy consumption by 7% from 2011 to 2016. However, the increase by share of natural gas and non-fossil fuels, meanwhile, was equal to 10% of the increment led by economic growth. Although the total energy consumption is still increasing slightly, we consider the changes in these provinces to be successful transitions given the

"cleaner" nature of natural gas and non-fossil fuels in their climate and air pollution impacts.

## STRUCTURAL DECLINES OR NOT

The observed declines in consumption are encouraging, but it is important to know the possibility of sustaining such trends. If there is a structural break in the consumption pattern, the nascent decline is likely to last and can be interpreted as a "structural decline."[3] Here, an econometric (cumulative sum) test was used to identify structural break points in provincial energy consumptions from 2003 to 2016.

For the 14 provinces analyzed above, unfortunately, only two of them (Shanghai and Hubei) have structural breaking points during the period from 2011 to 2016. This finding suggests that the strong decreasing forces featured by energy intensity and, to a lesser extent, by the change of industrial structure and share of coal are likely to be sustained. Regarding the other provinces, the changes in their energy drivers are not structurally significant.

## FUTURE REDUCTION PATHWAYS

The non-structural changes indicate two potential reduction pathways. One path is to sustain the strong decreasing effect mainly from energy intensity. It might be applicable to Hebei, Liaoning, Jilin, Henan, Hubei, and Yunnan, whose energy intensities are still high (~3.0–5.8 tce/$10^4$ USD in 2016). The other path is to complement energy intensity with new decreasing drivers. It better suits the other eight provinces, which have achieved relatively low levels of energy intensity. Their energy intensities were reduced by 34% from 2011 to 2016, whereas the average rate for the other provinces was 24%. By 2016, the energy intensities of these eight provinces were among the lowest in China and were even comparable to that of the United States, although their per capita GDPs were only ~20%–30% of that of the United States. A prominent example is Beijing. With a per capita GDP at 30% of that of the United States, the energy intensity in Beijing by 2016 was 7% lower than that of the United States. To maintain decreasing drivers neck and neck with economic growth, the decreasing effects from energy mix and, to a lesser extent, from industrial structure should be exploited.

The above suggestion is also because of the observation that energy intensity reduction seems to be a low-hanging fruit achievable even by less-developed provinces. Although new drivers that decrease consumption, i.e., share of coal and industrial structure, are emerging, a thorough review of the energy drivers from 2003 to 2016 in Chinese provinces shows that energy intensity was always the first driver of reduction that developed and applicable to provinces in various development states. Figure 2 illustrates the evolution of energy drivers for a province with an initial decline in consumption (e.g., Chongqing in Figure 2A) and for provinces with growing consumption (e.g., Shaanxi in Figure 2B and Inner Mongolia in Figure 2C). Figure 2A shows how the decreasing effect of energy intensity emerged in Chongqing and quickly intensified to a magnitude comparable to that of economic growth, accompanied by the emergences of new drivers such as share of coal. Shaanxi and Inner Mongolia also reflect the enhancement of energy intensity but at a much slower rate. The effects from industrial structure change and share of coal were minor or even increasing. In addition, a reduction in energy intensity did not severely compromise economic growth. Provinces with increasing consumption were able to reduce their energy intensity by 7% while maintaining an 8% GDP annual growth from 2011 to 2016. As the Energy Supply and Consumption Revolution Strategy (2016–2030) (hereinafter referred to as the Strategy)[10] was launched in 2016, China will further reduce its energy intensity by 15% from 2015 to 2020. Such a reduction is less than the 23% achieved from 2011 to 2015, indicating that energy intensity might not be as strong of a decreasing driver as it was in the past. Further reduction in energy intensity should be mainly achieved by less-developed provinces with growing consumption.

Part of high-energy intensities of less-developed provinces is attributed to their locations in the upstream of supply chain as energy suppliers and heavy industrial goods producers.[11] For example, approximately 34% of the electricity produced in Inner Mongolia was sent out to other provinces in 2016. The less-developed provinces will benefit from demand-side adjustments and decoupling from energy in developed provinces. Nevertheless, local technological improvements might be more practical in the short term and benefit the greener growth of China as a whole. A dynamic market for energy-saving technologies has been developed in China with 5,800 energy service companies and energy performance contracts worth 15 billion USD.[12] As a way to apportion the responsibility, subsidies from other downstream provinces with greater ability to pay might be considered to fasten technological improvement in these supporting provinces.

The Strategy also targets the share of cleaner fuels (natural gas and non-fossil fuels) and production overcapacities. By 2030, the share of cleaner fuels should reach 35%, doubling the level in 2016. The share of coal and petroleum, in other words, will be capped at 65%. The decreasing effects from share of coal and petroleum could be greatly enhanced.[13] This is especially true for the provinces with declined consumption, whose reduction potentials from energy intensity are depleting. Their greater ability to

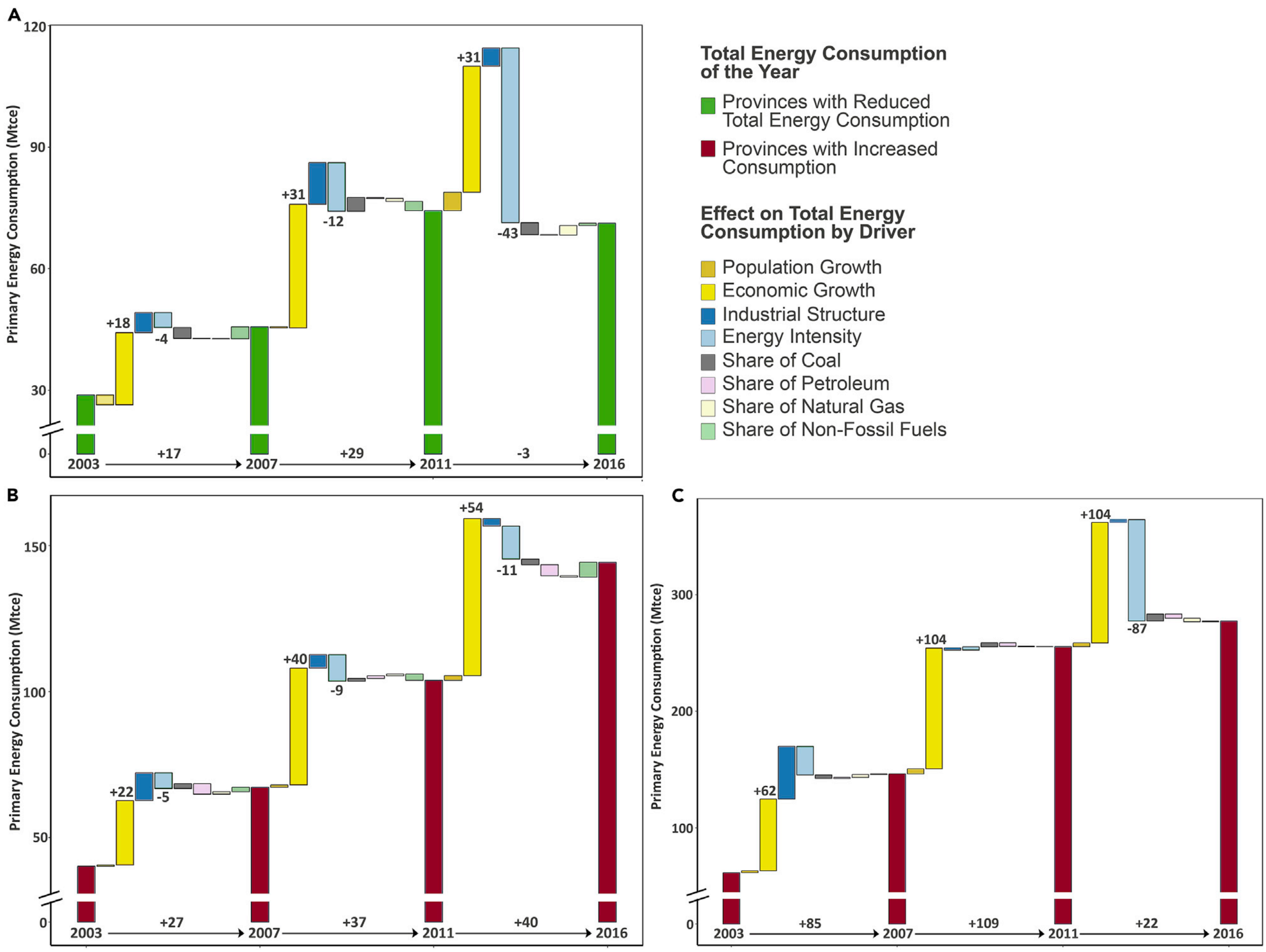


**Figure 2. Evolutions of Energy Drivers in Different Provinces**

Often a prevailing driver of decreased energy consumption, the impact of energy intensity is intensified across provinces with reduced consumption (e.g., Chongqing in A) as well as those with increased consumption (e.g., Shaanxi in B and Inner Mongolia in C). However, the process is faster in the former ones, accompanied by the emergences of new drivers that reduce consumption, such as industrial structure change and share of coal.

pay and pressure on pollution alleviation also urge the transition. Phasing-out overcapacities are also highlighted in the Strategy, targeting inefficient capacities in coal mines, iron and steel, and cement industries. The decreasing effect of industrial structure might emerge in those energy-supplying provinces and heavy industrial hubs, such as Heilongjiang, whose share of heavy industries decreased from 23.9% in 2011 to 17.3% in 2016. The decreasing effect of industrial structure change on energy consumption (25 Mtce) even exceeded that of energy intensity (9 Mtce) from 2011 to 2016.

The total energy consumption of China will be capped at 5,000 Mtce and 6,000 Mtce by 2020 and 2030, respectively. The annual growth, as a result, must be no higher than 1.8%, comparable to the growth from 2011 to 2016 (1.7% annually). To achieve such a low growing rate, energy consumption of some provinces need to be reduced, or at least, plateaued. China should endeavor to secure the initial declines observed in some of its provinces and foster energy efficiency improvement and industrial reconstruction for more energy-efficient growth in the less-developed provinces.

## SUPPLEMENTAL INFORMATION

Supplemental Information can be found online at https://doi.org/10.1016/j.joule.2019.03.007.

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COMMENTARY

# Avoiding the Hype in Developing Commercially Viable Desalination Technologies

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Hype often drives the research agenda in any field. A new technology that promises to solve a major problem facing humanity emerges. Data are published, and the press and public relations machines enter into high gear. Stories are written, social media explodes, and the researchers are elevated to rockstar status. More often than not, however, these technologies fail to meet expectations. They may be applied to the wrong field, be in too early a stage in their development, have few pathways for scale-up, or simply be uncompetitive with existing technologies.

These stories often follow the Gartner Hype Cycle[1] (see Figure 1), where interest in a technology rapidly grows after a "technology trigger" and peaks at a point of "inflated expectations" before collapsing into a "trough of disillusionment" when the technology fails to deliver on its promises. The technology slowly recovers as its best use is ultimately found through what is known as the "slope of enlightenment," and some level of commercial success ensues ("plateau of productivity"). This cycle can be overlaid with academic research quite easily. An early-stage success at a respected research institution or a publication in a respected journal triggers a flood of academic research activity all around the world. Funding is procured, programs are established, students are trained, post-doctoral researchers are hired, faculty give keynotes, conferences offer symposiums, and start-up companies are spun out of universities with government and private funding. Then, when the technology fails to meet expectations, the interest and buzz collapse, often quickly, leading to a damaging shift in priorities and resources.

The desalination research field is not immune to this cycle. The press

 